RiversEdge West Meeting
March 3-5, 2026 IP-183507

Revisiting tamarisk biocontrol in the western United States: ecological and societal implications

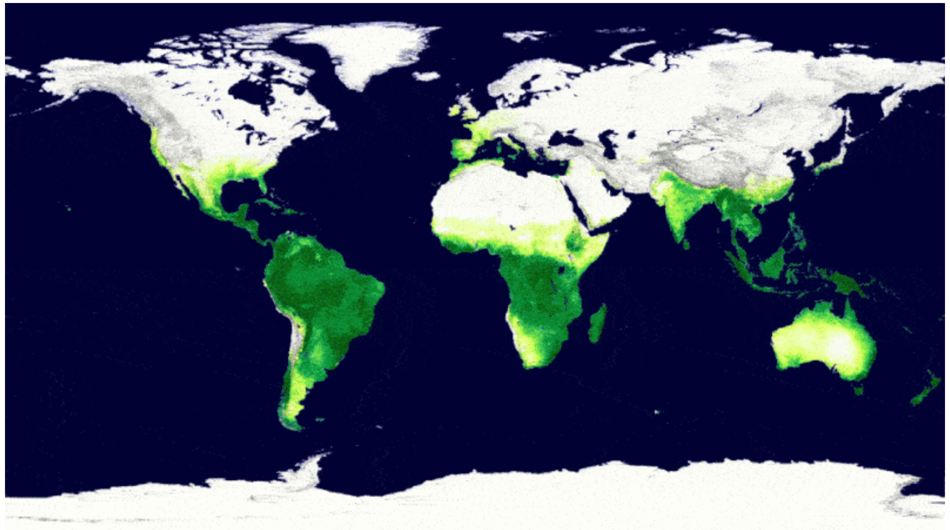
Nagler, Pamela, Emily Palmquist, Keirith Snyder, Matthew J. Johnson, Mary Anne McLeod, Eduardo Jimenez-Hernandez, Christian Edwards & Kevin R. Hultine

[1] **U.S. Geological Survey**, Southwest Biological Science Center, Tucson, AZ USA; pnagler@usgs.gov

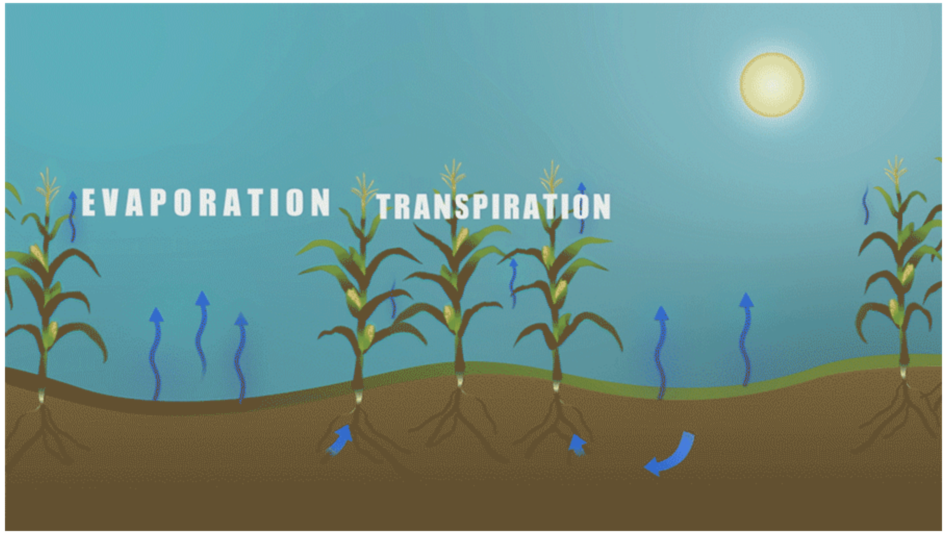
U.S. Department of the Interior
U.S. Geological Survey

Hypothesis

H_0: Vegetation health and water consumption are showing declining trends in riparian corridors in the U.S. Southwest.



A vegetation index (VI) is an estimate of plant “greenness” or plant health, it is composite estimate of canopy density, leaf size, plant maturity, and the intensity of photosynthesis activity.



Evapotranspiration (ET) is an estimate of the amount of water that is being transferred to the air from soil evaporation and transpiration from the plant leaves.

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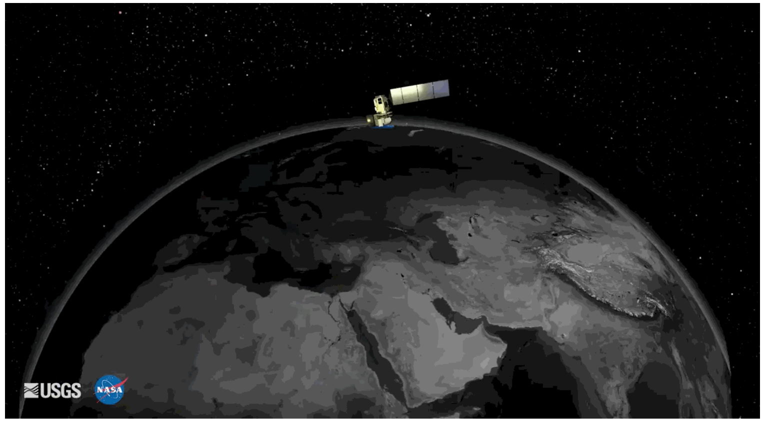
Metrics Measured: Riparian Areas Along the Lower Colorado River

- A vegetation index (VI) is an estimate of plant "greenness" or plant health, it is composite estimate of canopy density, leaf size, plant maturity, and the intensity of photosynthesis activity.
    - VI values go from -1 to 1 (0-1 is the useful range); zero indicates bare soil with no plants, and 1 is for dense and healthy green vegetation.
    - There are several vegetation indices, and the most widely used are the *Normalized Index Vegetation Index* (NDVI) and the *Enhanced Vegetation Indices* (EVI and EVI2).
- Evapotranspiration (ET) is an estimate of the amount of water that is being transferred to the air from soil evaporation and transpiration from the plant leaves. It reflects plant access to water, stress from drought, and consequently plant productivity and vigor.
    - Actual ET (ETa) is how much the land surface evaporates and transpires.
    - Potential ET (ETo) is the maximum amount of water the land surface loses in ET.
- ET is measured as a column of water (mm^3/mm^2 = mm per day (also in inches per day)) that is transferred to the atmosphere.
- We are utilizing data from the Landsat 8 satellite mission and Nagler's ETa equation to estimate these values.
- Combined VI and ET capture the plants/ecosystem health, service, function, resilience, and stress.

Remote Sensing Data Acquisition and Processing Pipeline

- Data from the Landsat mission (USGS)
  - Spatial resolution: 30 m (~100 ft)
  - Temporal resolution: 16 days
- Period 2000 – 2024: Landsat 5, 7, & 8



Landsat Data Acquisition & Mosaicking → Quality Assessment → Vegetation Indices → Long-Term Averages → Spatiotempo-ral Gap Filling → Reference ET (ET_0) → Actual ET (ET_a) → Mask of Riparian Areas → Time Series Analysis

*Current step

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

$$EVI = G \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + C1 \cdot \rho_{Red} - C2 \cdot \rho_{Blue} + L}$$

$$EVI2 = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 2.4 \cdot \rho_{Red} + 1}$$

$$ET_a = ET_0 \cdot 1.65\left(1 - e^{-2.25(EVI2)}\right) - 0.169$$

Nagler *et al.* (2009), Nagler *et al.* (2013), & Nagler *et al.* (2022)

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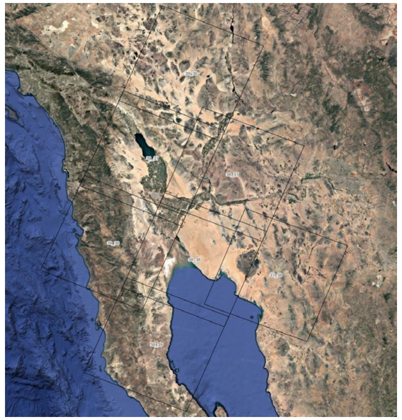
Study Areas selected: Lower Colorado River Basin Riparian Corridors

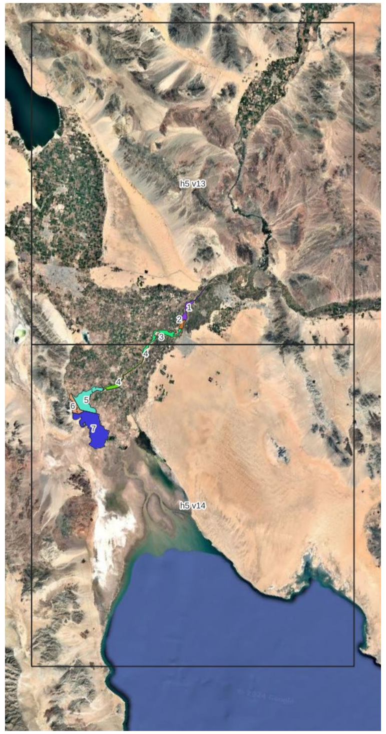
Study Sites

- **Lower Colorado River Basin Riparian Reaches**

Mosaicking: from Landsat scenes to ARD tiles

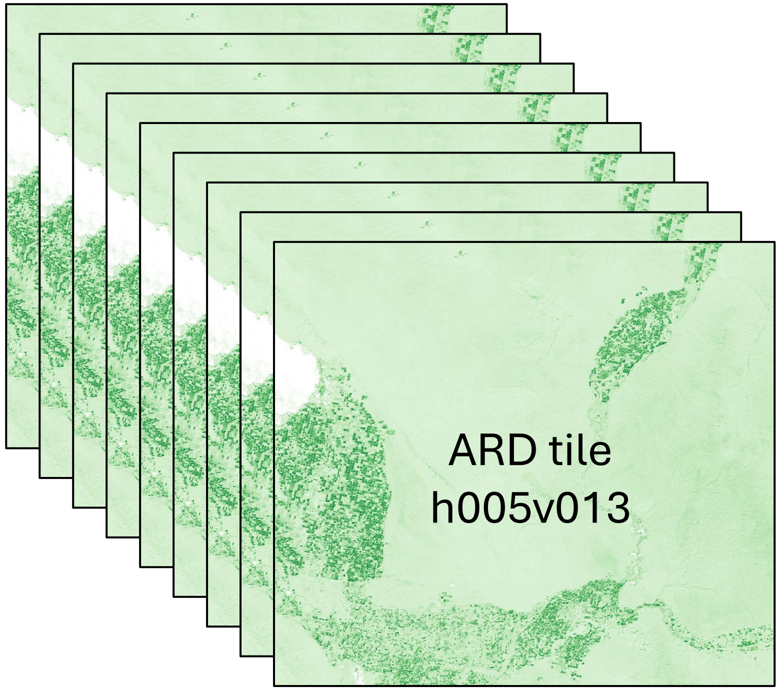


Landsat UTM 11



Albers Equal Area Conical

Processing – Storage (data cube)



- **ARD tiles each 16 days**
- **23 files per year**
- **Tiles are 150x150 km**
- **5000x5000 Landsat pixels**
- **Smaller areas are extracted with a mask**

Day-of-year

LANDSAT08.A2023012.h005v014.hdf
LANDSAT08.A2023028.h005v014.hdf
LANDSAT08.A2023044.h005v014.hdf
LANDSAT08.A2023060.h005v014.hdf
LANDSAT08.A2023076.h005v014.hdf
LANDSAT08.A2023092.h005v014.hdf
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LANDSAT08.A2023140.h005v014.hdf
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LANDSAT08.A2023316.h005v014.hdf
LANDSAT08.A2023332.h005v014.hdf
LANDSAT08.A2023348.h005v014.hdf
LANDSAT08.A2023364.h005v014.hdf

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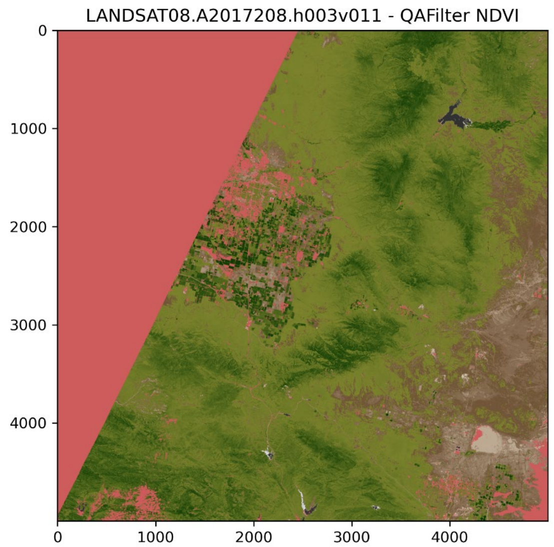
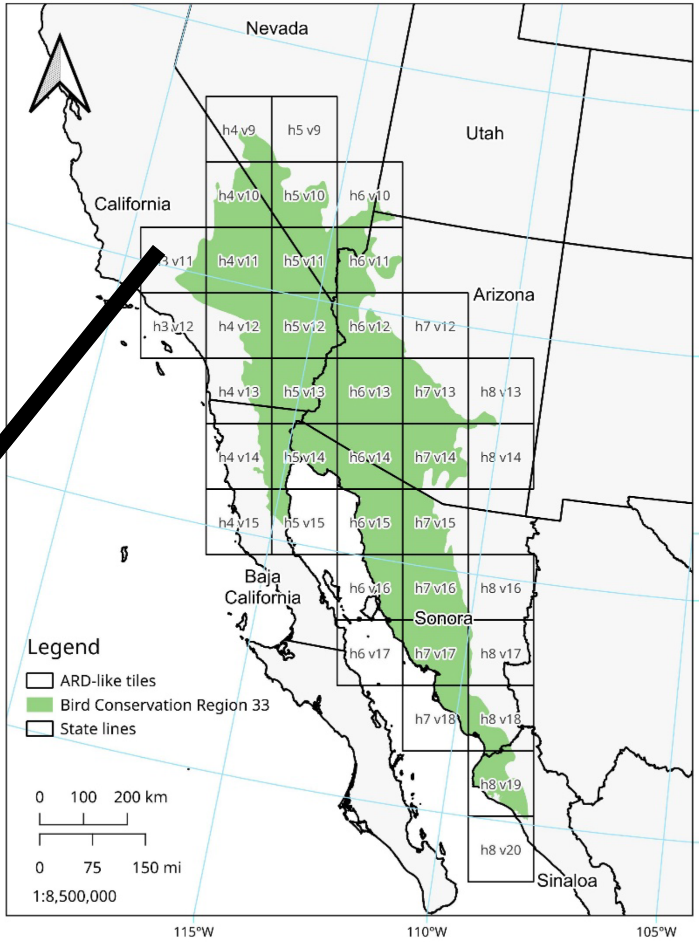
Vegetation Indices & Quality Assessment

- **FILTER1**: Quality Assessment filtering (MODIS-like)
  - Removal of pixels w/clouds, cloud shadow, high aerosols
- **LTAVG**: Long term averages (e.g., Landsat OLI 2013-2022)
  - Descriptive statistics: mean, std deviation, min, max
  - Averages could be computed for any period (3, 5 or full record)
- **FILTER2**: Smoothing and removal outliers
  - Use long term averages to smooth the signals
  - Gap filling (temporal and spatial)
- **CONTINUITY:** seamlessly transition Landsat 5 -> 7 -> 8



ARD tiling system



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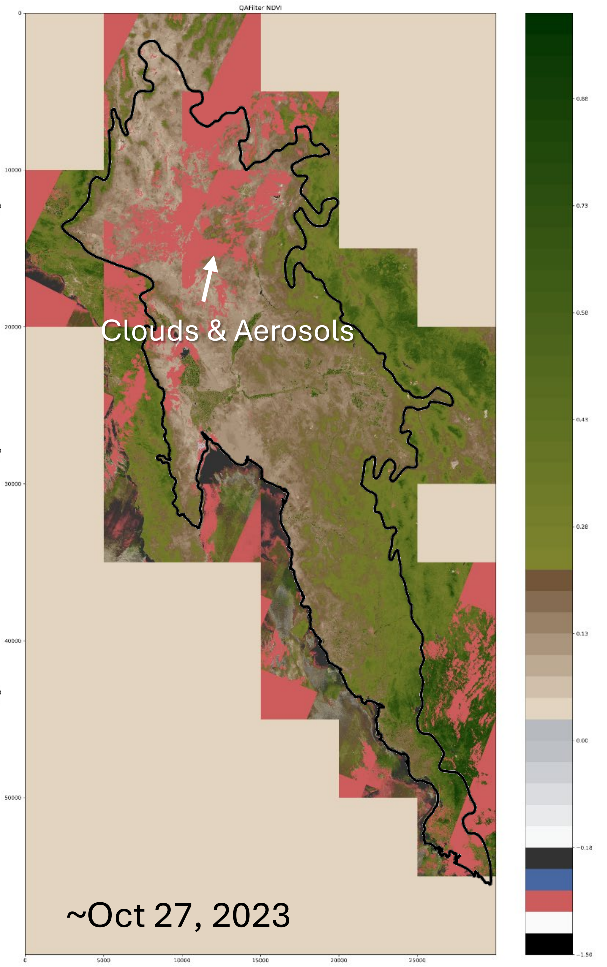
Data processing in 38 tiles Landsat U.S. Analysis Ready Data (ARD)

QA removes bad quality pixels:

Clouds & high aerosol removed



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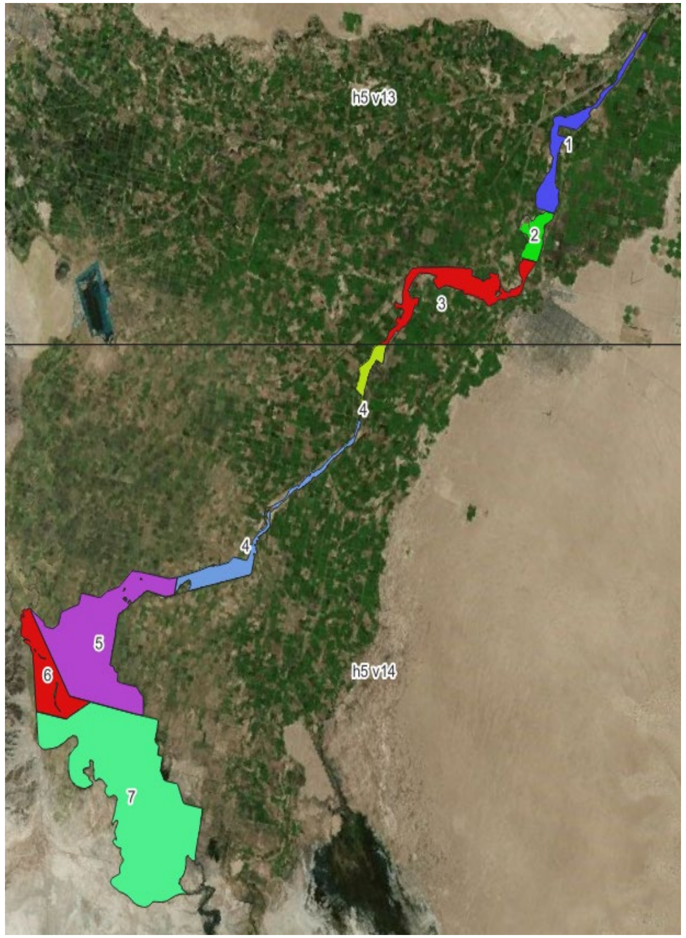
Calculation of VI and ET (based on EVI2) Time-Series Data

ETo Calculate ETo (Blaney-Criddle) using Daymet or from ground-station meteorological data obtained from AZMET data (Penman-Monteith)
Smooth the ETo using 8-day before and after the satellite overpass date

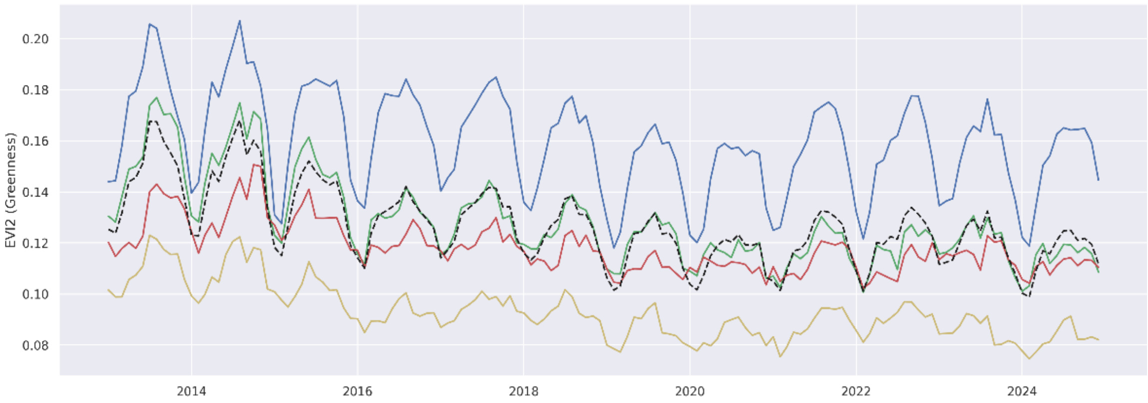
ETa: Transform Landsat into MODIS-like data to apply Nagler's ET 2020 equation

- **In previous work, we have extracted time series for riparian areas across the U.S. Southwest.**
- **Next step is replicating this work using Machine Learning algorithms to extract riparian corridors and defoliated areas from Tamarisk beetle.**



Example Time Series

Lower Colorado River Delta



Nagler *et al.*, (2025) IP-176865

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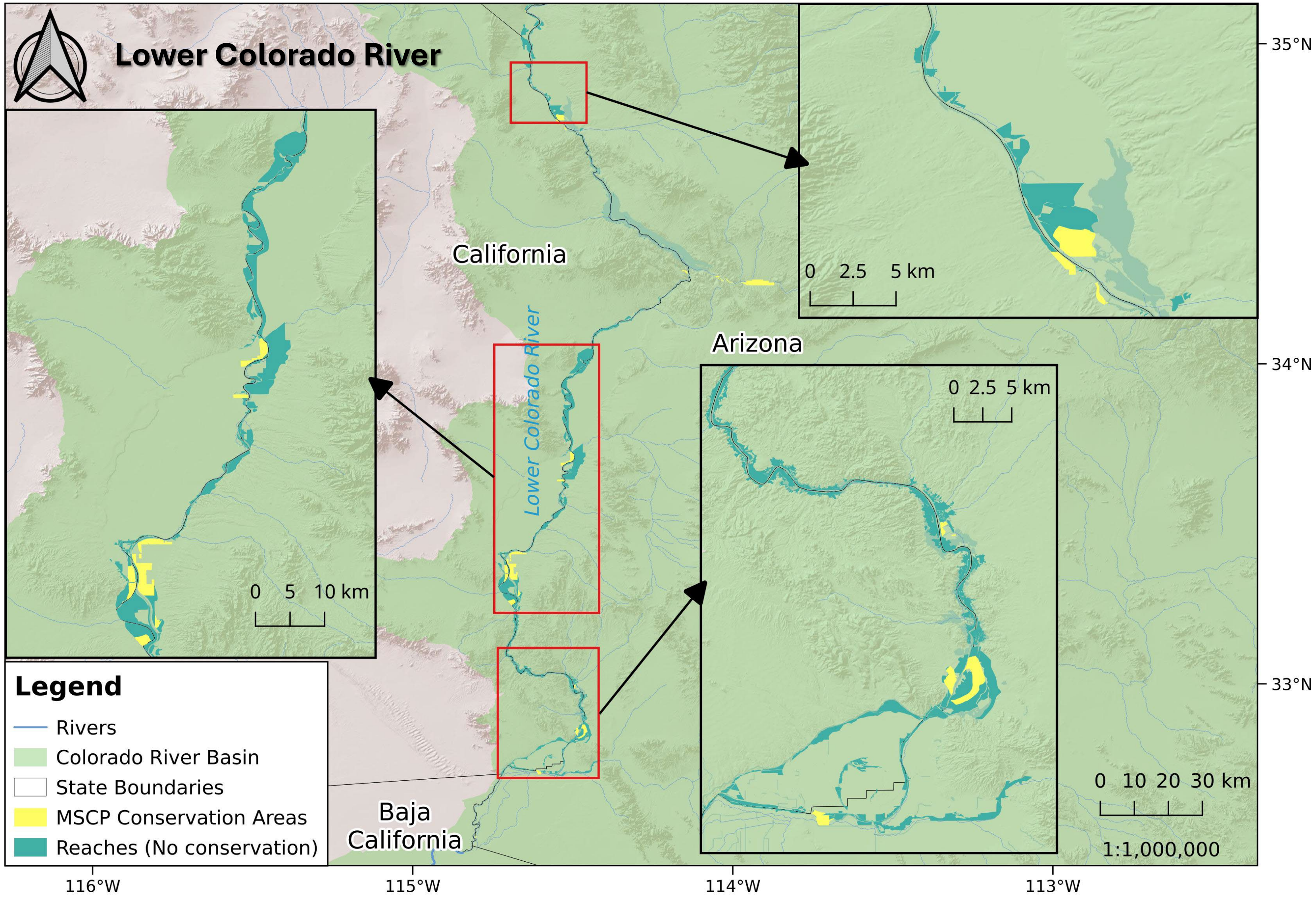
Example using known Riparian Sites: Lower Colorado River



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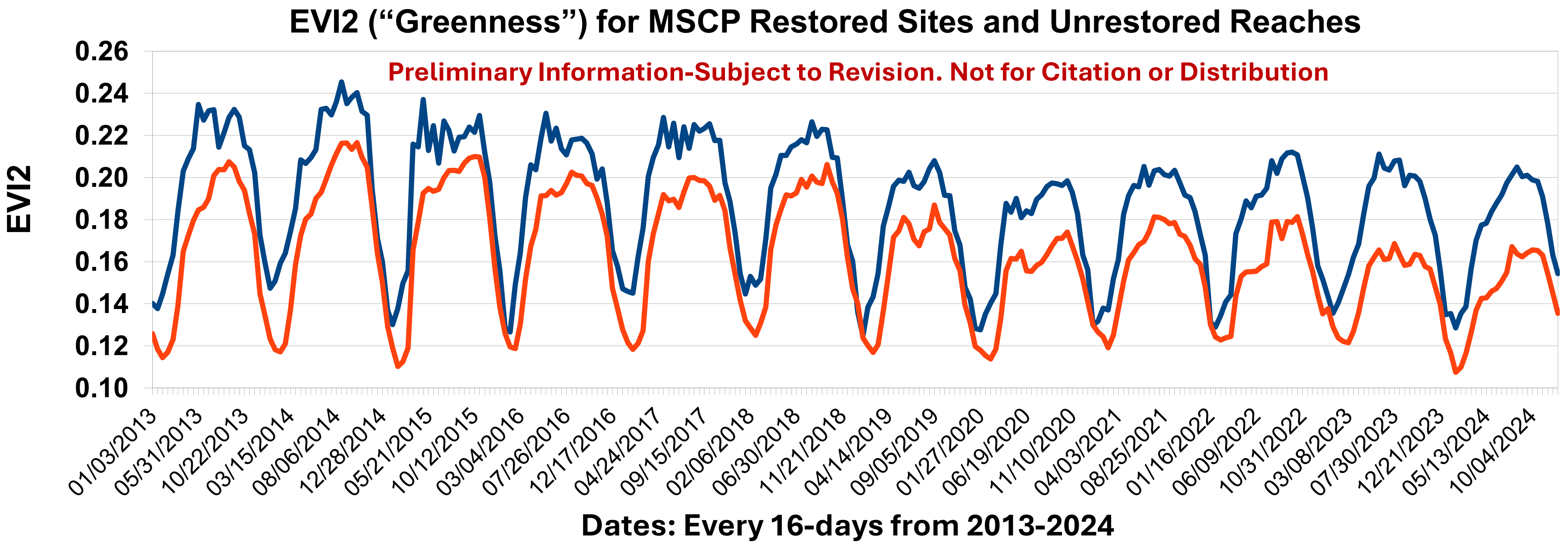
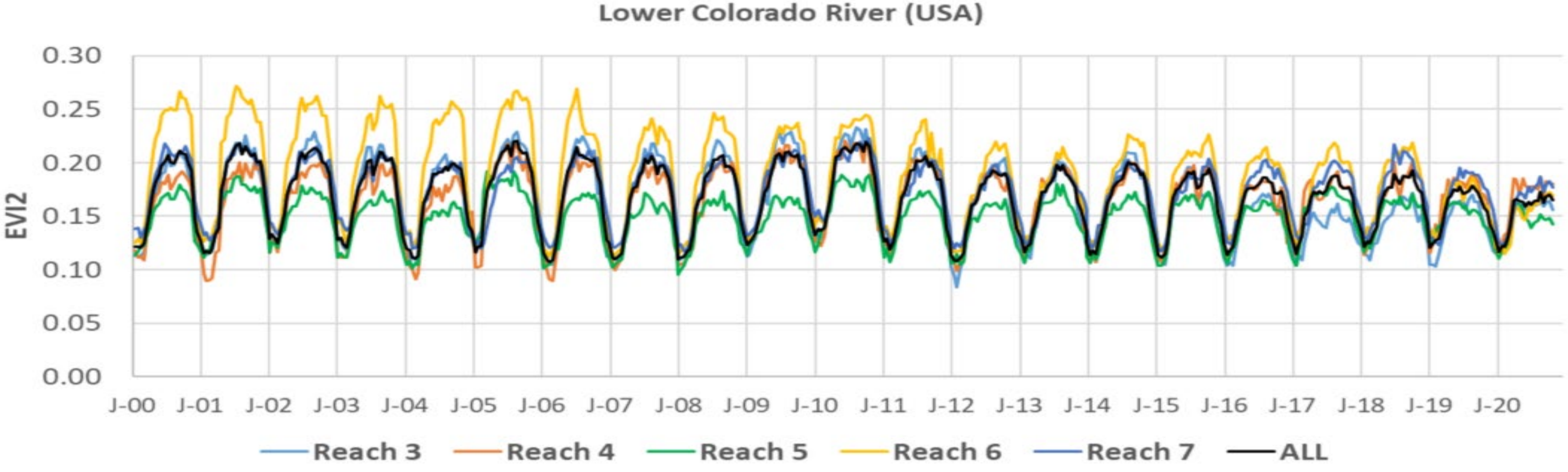
Enhanced Vegetation Indices (EVI2) ("Greenness")





Nagler et al. (2021)

	MSCP EVI2	Reaches EVI2
2013	0.20	0.17
2024	0.17	0.14
Difference Loss	-0.02	-0.02
Change (%)	-12.20	-14.41

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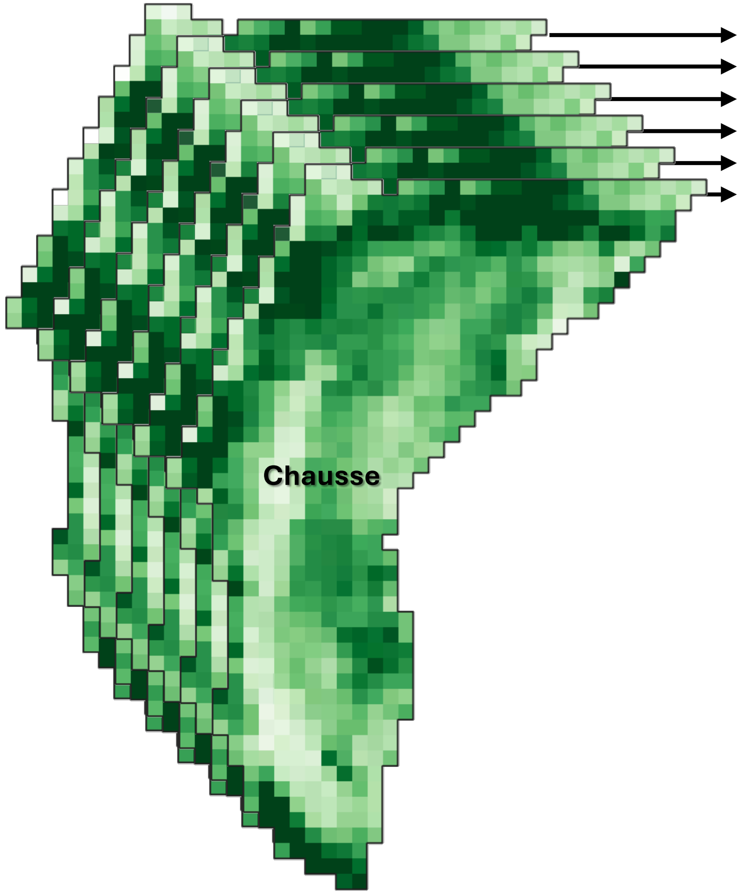
Creation of Time-Series Data

- From 2013-2024:
- 1 image @ 16 days

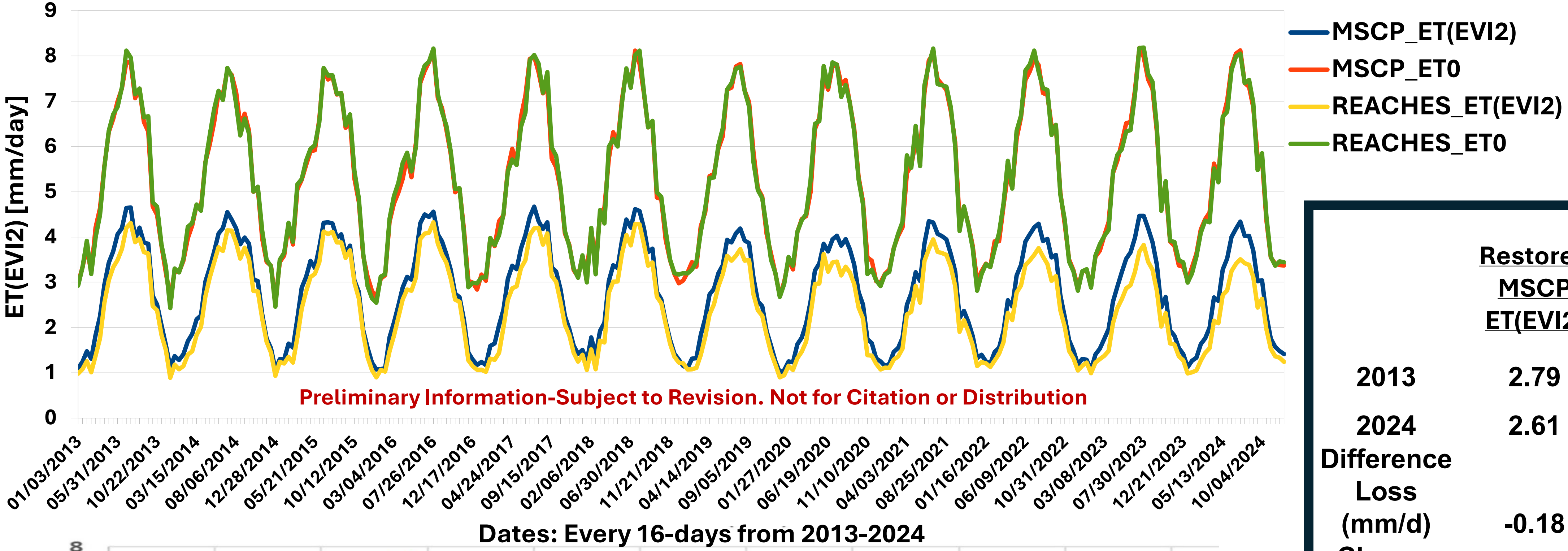
- Repeat for:
  - EVI
  - EVI2
  - ETo
  - ET(EVI)
  - ET(EVI2)

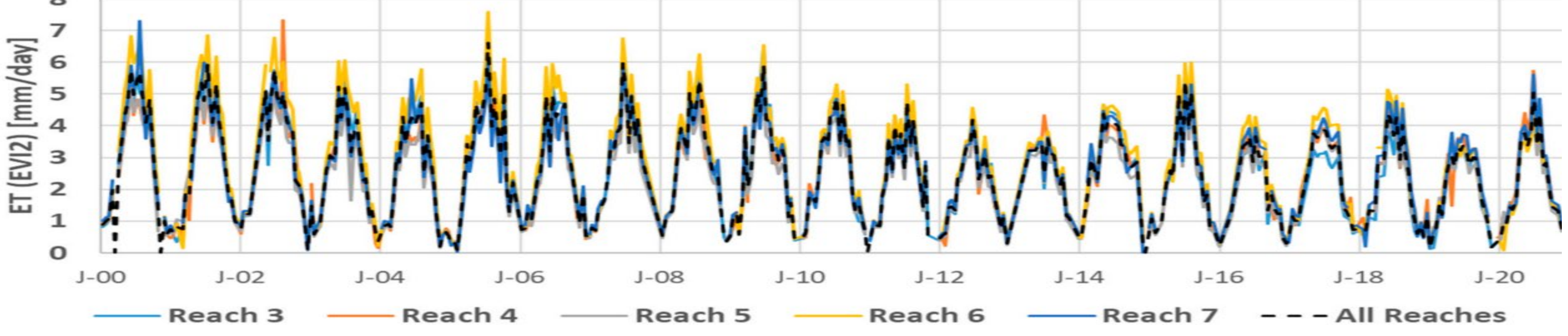


		NDVI					
YEAR	DOY	DATE	MIN	MAX	AVG	STDEV	NPIXELS
2013	8	1/8/2013	1090	5672	3409.45	981.80	704
2013	24	1/24/2013	995	5132	2906.72	799.85	704
2013	40	2/9/2013	1149	5490	3141.87	868.96	704
2013	56	2/25/2013	940	5343	3055.09	869.41	704
2013	72	3/13/2013	1249	5322	3045.13	835.52	704
2013	88	3/29/2013	1092	6362	3687.29	1066.62	704
2013	112	4/22/2013	1225	6006	3507.37	1049.84	704
2013	120	4/30/2013	1185	5920	3552.38	1013.14	704
2013	144	5/24/2013	1183	6515	3516.65	1146.81	704
2013	160	6/9/2013	983	6529	3710.10	1201.52	704
2013	176	6/25/2013	1058	6672	3676.85	1240.45	704
2013	192	7/11/2013	1454	6498	3538.08	1000.40	704
2013	208	7/27/2013	1108	7453	4168.79	1358.61	704
2013	224	8/12/2013	1050	7486	4028.81	1367.20	704
2013	240	8/28/2013	1216	7239	4029.54	1207.77	704
2013	256	9/13/2013	905	7809	4223.64	1464.73	704
2013	272	9/29/2013	707	7712	4151.30	1469.55	704
2013	288	10/15/2013	790	7670	4075.12	1383.42	704
2013	304	10/31/2013	961	7630	3995.93	1368.78	704
2013	320	11/16/2013	825	7478	3710.06	1233.79	704
2013	336	12/2/2013	834	7580	3493.40	1139.37	704
2013	352	12/18/2013	934	6126	3106.85	977.19	704
2013	360	12/26/2013	985	5894	3091.43	920.23	704
2014	3	1/3/2014	928	5800	3184.66	947.96	704
2014	19	1/19/2014	895	4910	2722.01	748.58	704
2014	35	2/4/2014	1008	5565	3030.21	824.33	704
2014	51	2/20/2014	947	6152	3010.84	786.54	704
2014	67	3/8/2014	1165	6487	3176.35	840.72	704
2014	83	3/24/2014	1157	7126	3546.40	1027.22	704
2014	99	4/9/2014	991	6374	3297.90	1005.14	704

Evapotranspiration (mm/day) with EVI2 (“Water Use”)

ET(EVI2) for MSCP Restored Sites and Unrestored Reaches





Nagler et al. (2021)

	Restored MSCP ET(EVI2)	Unrestored Reaches ET(EVI2)
2013	2.79	2.50
2024	2.61	2.16
Difference Loss (mm/d)	-0.18	-0.34
Change (%)	-6.38	-13.69

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Summary of Findings

	MSCP_ET0	REACHES_ET0	MSCP_ET(EVI2)	REACHES_ET(EVI2)	MSCP_EVI2	REACHES_EVI2
2013	5.21	5.25	2.79	2.50	0.20	0.17
2024	5.34	5.30	2.61	2.16	0.17	0.14
Difference	0.12	0.05	-0.18	-0.34	-0.02	-0.02
Change (%)	2.35	0.89	-6.38	-13.69	-12.20	-14.41

The Differences in ET are losses in water use and reported in mm/d; i.e., -18 mm/d MSCP & -34 mm/d Unrestored Reaches

Reaches without MSCP: 29,595.958 ha
MSCP: 6,078.534 ha

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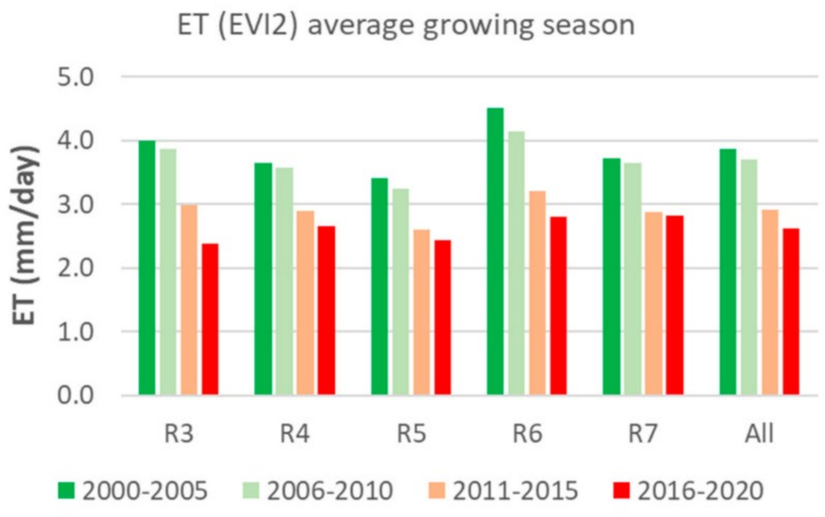

Nagler et al. (2021)

Declines in both Riparian Corridor Greenness and ET continue through 2024.

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Monitoring the Impact of Biocontrol: In a Nutshell

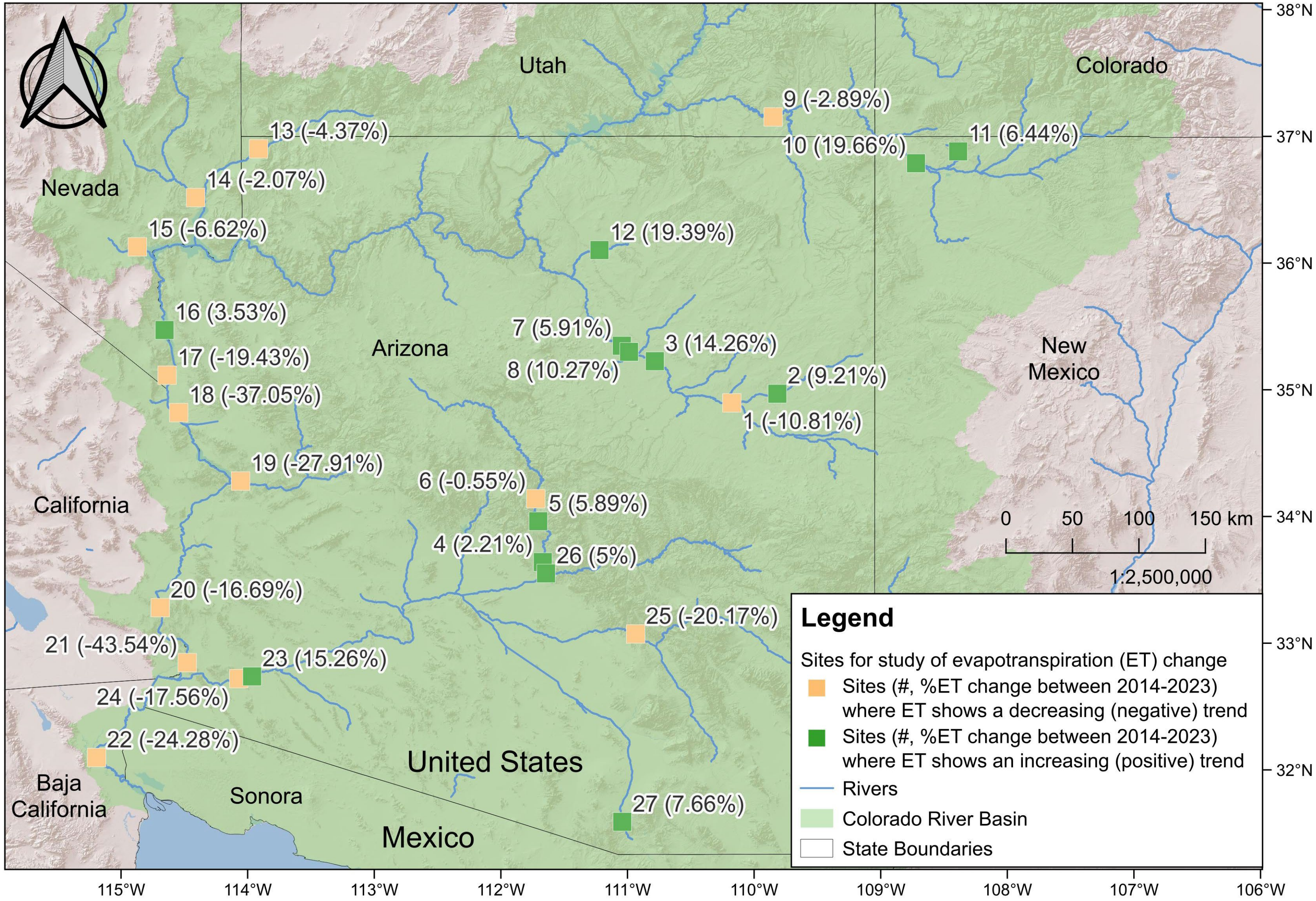
In our effort to re-examine the ramifications of tamarisk control following the Hultine et al. (2010) assessment, we acknowledge that the biological complexity of riparian ecosystems and the vast geographical scope of tamarisk biological control make any predictions about how riparian forests across the western U.S. will look and function in the future subject to numerous caveats.

We review the current knowledge of one of the most consequential biological control programs ever implemented in North America. We evaluate:

1) **impacts on riparian ecosystem ET and riverine hydrology;**
2) **changes to ecosystem-scale carbon and nutrient cycling;**
3) **vegetation community dynamics and secondary invasions;**
4) **avian habitat quality and impacts on at-risk bird species.**

We assess current challenges and opportunities from tamarisk biocontrol and imagine how western US riparian forests may evolve with reduced tamarisk cover.

Tamarisk-related ET Changes due to Defoliation



Quick Look:
27 sites selected from where defoliation was evident during 2023 and tracked from 2013-2023

U.S. Geological Survey Data Release
https://doi.org/10.5066/P142ZSGY

Preliminary Information-Subject to Revision. Not for Citation or Distribution

Nagler et al. Submitted, in Review,
Frontiers in Ecology and the Environment

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BIRD Habitat Assessment

Quick Look: 27 sites selected from where defoliation was evident during 2023 and tracked from 2014-2023

No.	Site Name	ET 2014	ET 2023	Difference	Change (%)	Area (ha)	Longitude	Latitude
1	Little Colorado River at Holbrook	541.17	482.66	-58.51	-10.81	94.33	-110.1746	34.8972
2	Navajo Nation South	398.54	435.24	36.71	9.21	128.56	-109.8154	34.9695
3	Little Colorado R. East of Leupp	524.51	599.27	74.77	14.26	949.90	-110.7832	35.2265
4	Verde River N of Ft McDowell Yavapai NPWorks	856.68	875.63	18.95	2.21	530.48	-111.6685	33.6411
5	Verde River at Mesquite RA	934.87	989.98	55.11	5.89	93.81	-111.7042	33.9630
6	Verde River North	801.97	797.60	-4.37	-0.55	50.74	-111.7233	34.1407
7	Little Colorado River, East of Leupp	435.22	460.95	25.73	5.91	3.53	-110.9917	35.3048
8	Leupp	409.73	451.83	42.09	10.27	7.08	-110.9872	35.3001
9	San Juan River at Mexican Hat	443.87	431.02	-12.84	-2.89	14.76	-109.8487	37.1542
10	San Juan River at Shiprock	378.52	452.94	74.42	19.66	51.19	-108.7201	36.7889
11	Navajo Springs, NM	395.93	421.43	25.50	6.44	1.34	-108.3874	36.8820
12	Little Colorado River, Moenkopi Wash	597.14	712.93	115.79	19.39	23.83	-111.2203	36.1034
13	Upper Virgin River, Littlefield, Nevada	898.54	859.30	-39.24	-4.37	33.01	-113.9146	36.9026
14	Muddy River, Mormon Mesa, NV	693.65	679.28	-14.36	-2.07	158.65	-114.4105	36.5179
15	Las Vegas Wash NV	817.94	763.76	-54.18	-6.62	29.44	-114.8708	36.1290
16	Colorado River, Lake Mojave, AZ	535.52	554.44	18.92	3.53	61.43	-114.6564	35.4723
17	Colorado River, Big Bend State Park, NV	620.96	500.30	-120.66	-19.43	202.22	-114.6358	35.1157
18	Colorado River at Topock Marsh	798.05	502.34	-295.72	-37.05	3693.36	-114.5445	34.8200
19	Bill Williams R convergence w Colorado River	1055.13	760.66	-294.48	-27.91	290.77	-114.0553	34.2804
20	Lower Colorado River, Cibola NWR	726.56	605.31	-121.25	-16.69	1852.67	-114.6904	33.2808
21	Lower Colorado River Mittry Lake	991.54	559.84	-431.71	-43.54	348.56	-114.4768	32.8469
22	Lower Colorado River Delta, Lower Reaches, Kidney in Mexico	778.34	589.39	-188.96	-24.28	536.59	-115.1932	32.0982
23	Gila River, Quigley Wildlife Area	619.76	714.32	94.56	15.26	87.10	-113.9647	32.7384
24	Gila River, Wellton, AZ	889.97	733.69	-156.28	-17.56	654.11	-114.0701	32.7206
25	Gila River, S Kelvin Bridge to Kearney	970.09	774.39	-195.70	-20.17	195.40	-110.9347	33.0738
26	Salt River Convergence w Verde, AZ (Coon Bluff Recreation Area)	914.51	960.23	45.73	5.00	130.75	-111.6427	33.5513
27	Santa Cruz River @ Mavis Wash and Juan Bautista de Anza NHP	903.03	972.17	69.13	7.66	177.31	-111.0407	31.5907
	All Sites (n=27)	**701.18**	**653.37**	**-47.81**	**-6.82**	**385.22**	------	------
	Sites with Increases in ET (n=13)	**608.00**	**661.64**	**53.65**	**8.82**	**172.79**	------	------
	Sites with Decreases in ET (n=14)	**787.70**	**645.68**	**-142.02**	**-18.03**	**582.47**	------	------

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Not for Citation or Distribution

Nagler et al. Submitted, in Review, Frontiers in Ecology and the Environment

U.S. Geological Survey Data Release
https://doi.org/10.5066/P142ZSGY

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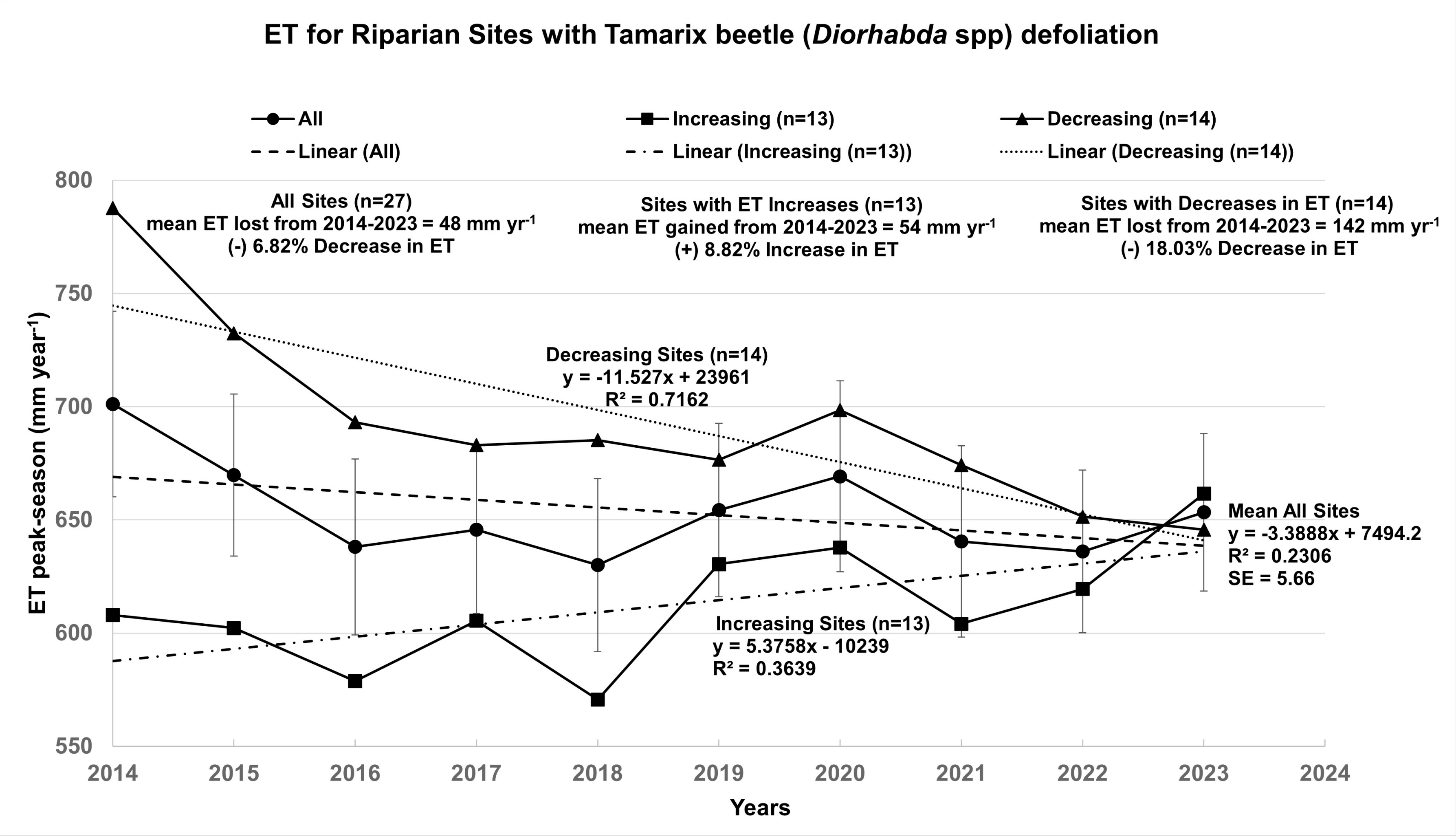
Tamarix spp. discriminated using defoliation in Time-Series Landsat



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Nagler et al. Submitted, in Review,
Frontiers in Ecology and the Environment

From 2014–2023, 52% of studied sites in the Colorado River Basin showed modest reductions in evapotranspiration (ET) from tamarisk biocontrol, while ET of remaining sites increased slightly, yielding inconsistent water savings.

U.S. Geological Survey Data Release
https://doi.org/10.5066/P142ZSGY

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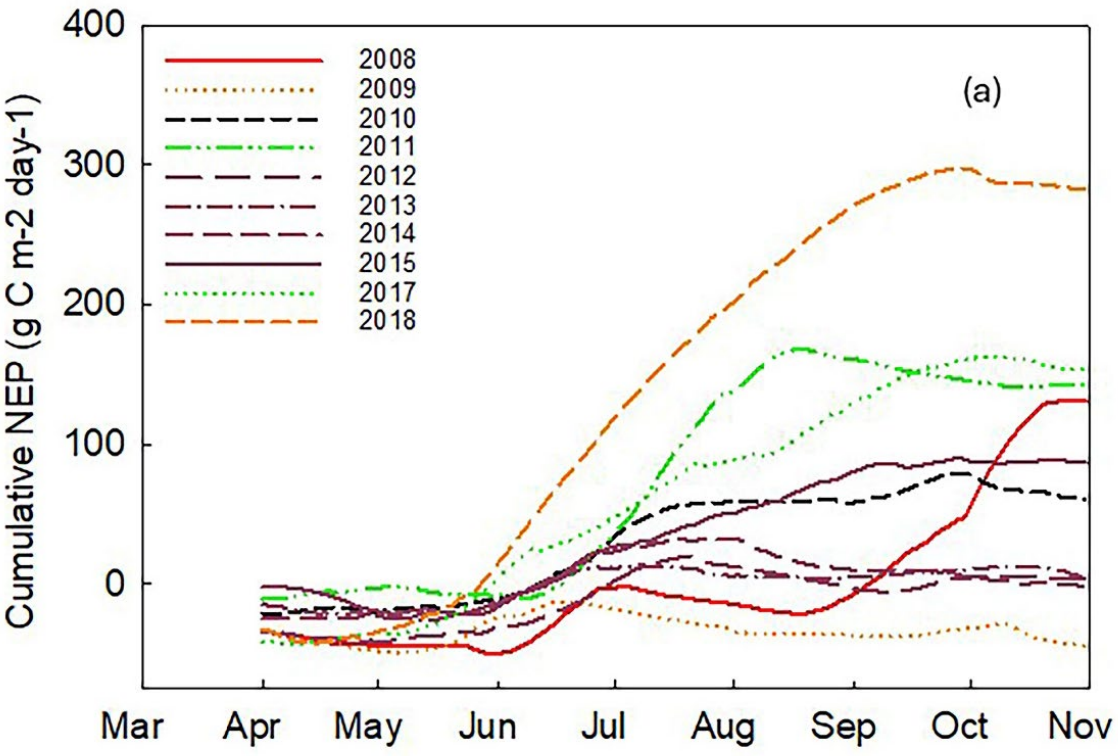
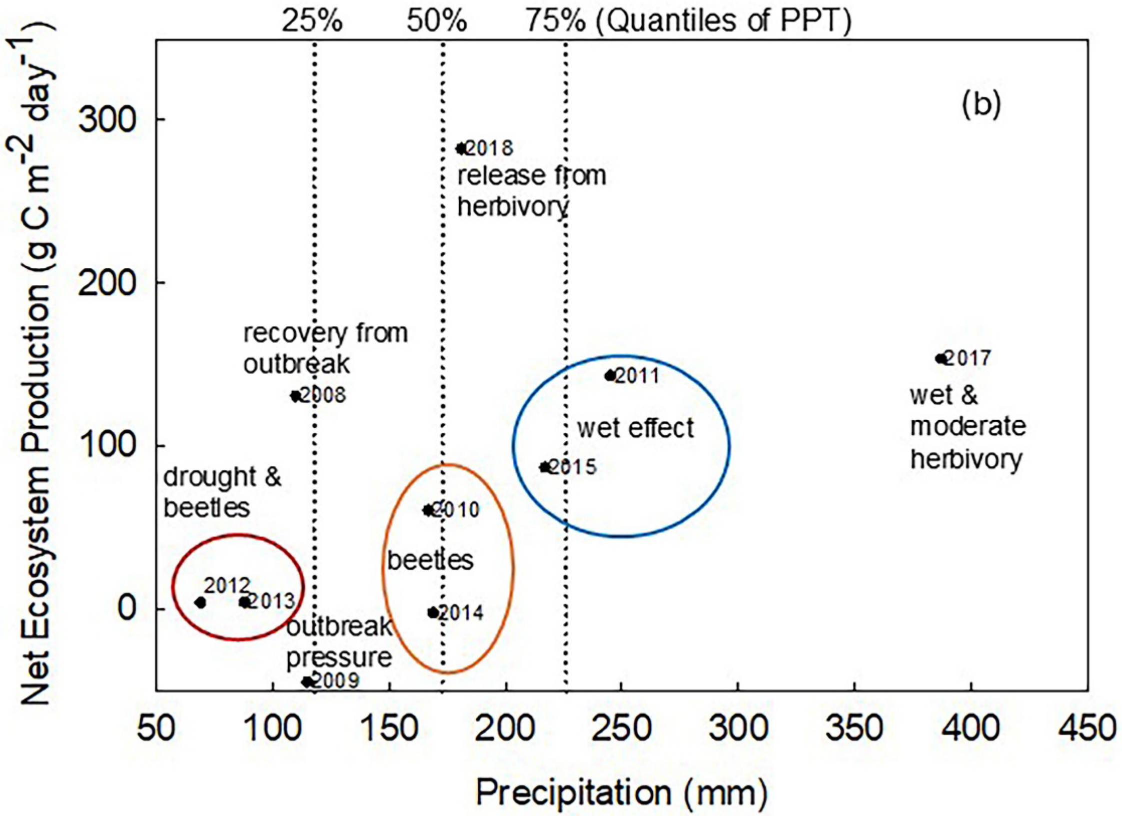
Cumulative and Net Ecosystem Production Assessment

Carbon and nutrient cycling accelerated during initial outbreak conditions, but successive years of defoliation did not produce directional cumulative impacts.





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Avian Habitat Assessment

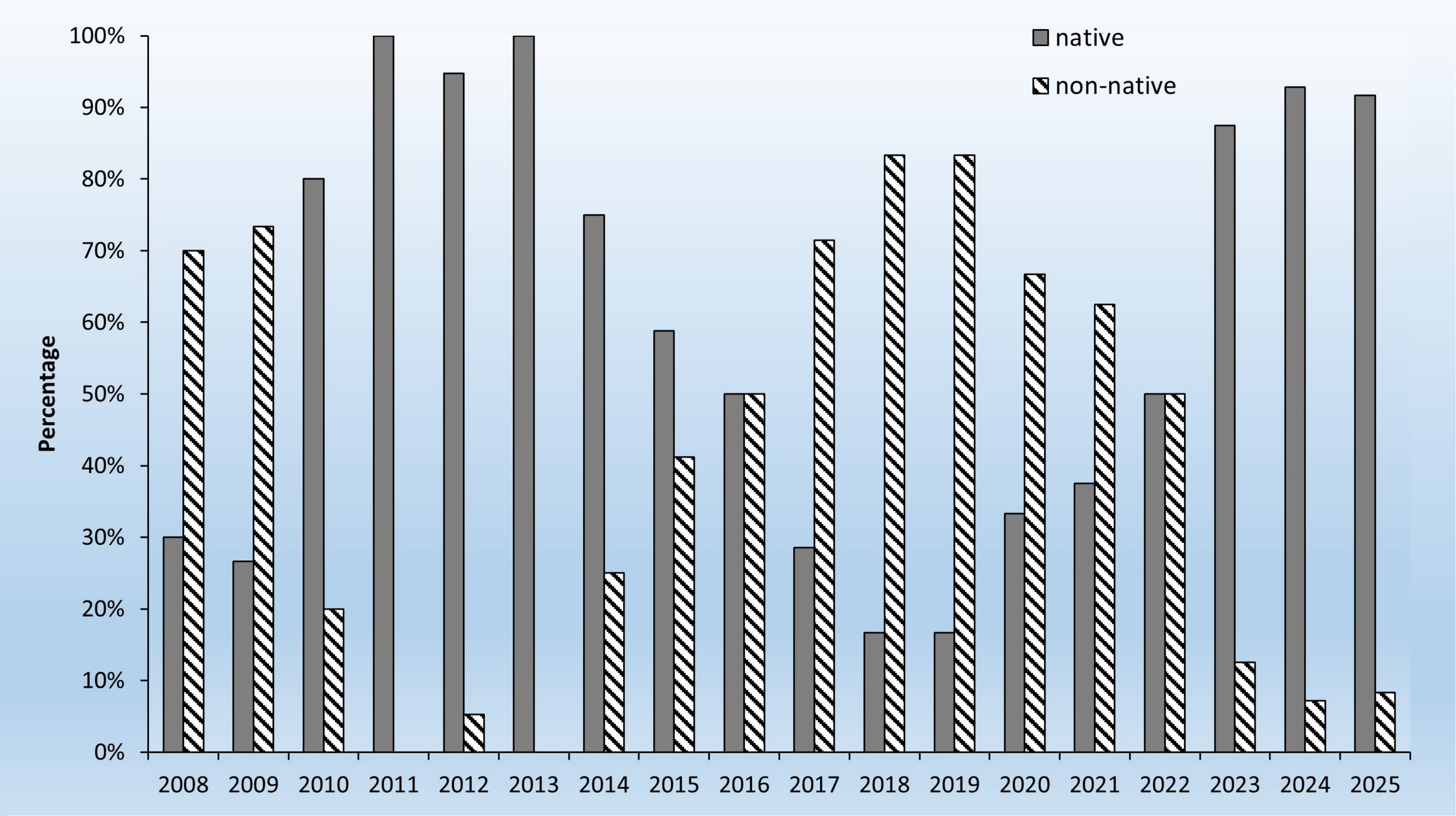
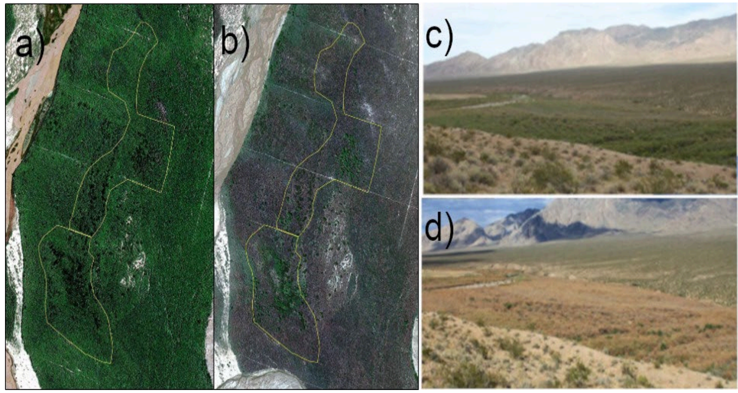


Figure 4. Southwestern Willow Flycatcher habitat shifting between native (ie willow) and non-native (ie tamarisk) dominated habitat during shifting defoliation periods from 2008–2025 along the upper Virgin River, Utah.



Beetle-impacted tamarisk stands support a depauperate avian community and negatively affect breeding in rare birds. Restored native vegetation provides important replacement habitat.

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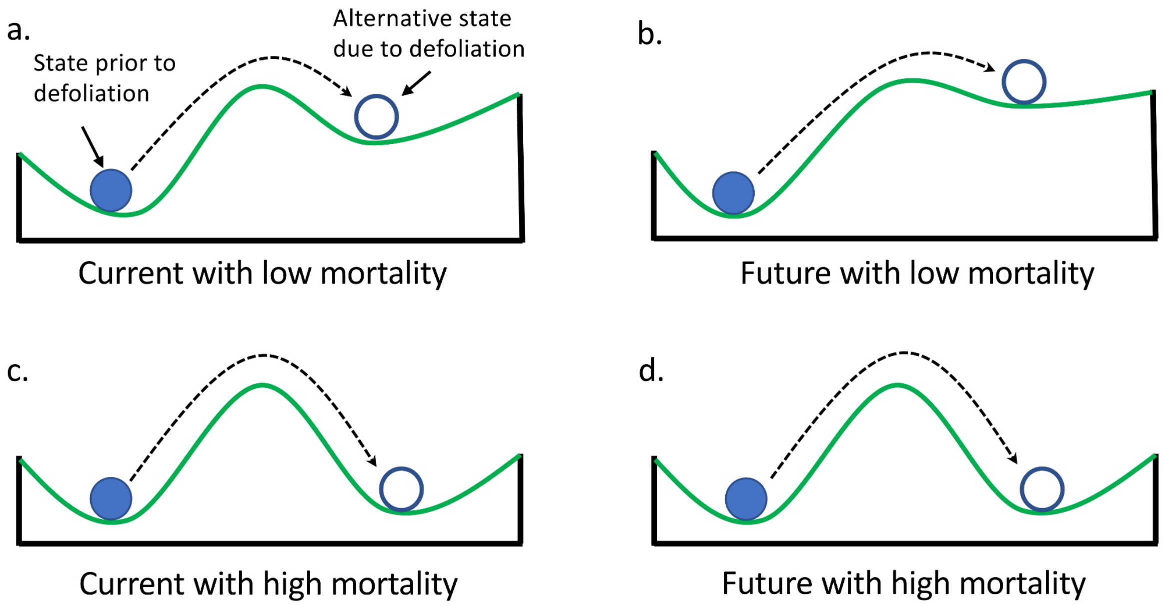
Conclusions I

Here are 4 scenarios after repeated beetle defoliation results in limited tamarisk mortality:

1) **In state 1, riparian ecosystems are moderately altered, with reduced tamarisk competitiveness reshaping plant community composition.**
2) **In state 2, a hotter, drier climate may destabilize this state as tamarisk exhibits high drought tolerance and reduced sensitivity to vapor pressure deficit, as well as deeper rooting relative to most native riparian trees.**
3) **In state 3, partial mortality today may thus translate into reduced mortality in subsequent years, reinforcing tamarisk dominance.**
4) **By contrast, in state 4, in locations where defoliation induces high tamarisk mortality, ecosystems are unlikely to revert to pre-invasion conditions, regardless of projected hotter and drier climates.**



Whether these alternative states are characterized by native riparian vegetation recovery or secondary invasive colonization will depend on hydrologic regimes and additional drivers beyond biological control.

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Summary of Findings

- Some river reaches now have more native shrubs where tamarisk cover has declined due to beetles (*Diorhabda* spp), but native tree recovery remains rare.
- From 2014–2023, 52% of studied sites in the Colorado River Basin showed modest reductions in evapotranspiration from tamarisk biocontrol, while evapotranspiration (ET) of remaining sites increased slightly, yielding inconsistent water savings.
- Carbon and nutrient cycling accelerated during initial outbreak conditions, but successive years of defoliation did not produce directional cumulative impacts.
- Beetle-impacted tamarisk stands support a depauperate avian community and negatively affect breeding in rare birds. Restored native vegetation provides important replacement habitat.
- In our effort to re-examine the ramifications of tamarisk control after the Hultine et al. (2010) assessment, we acknowledge that the biological complexity of riparian ecosystems and the vast geographical scope of tamarisk biological control will make any predictions regarding how riparian forests across the western US will look and function in the future require myriad caveats.

Conclusions II

- We reviewed the current knowledge of one of the most consequential biological control programs ever implemented in North America. While biological control offers an alternative to mechanical or chemical removal, the benefits from tamarisk biological control remain an open question.
- This conceptual framework omits three key factors:
    - (1) continued, variable tamarisk defoliation by beetles,
    - (2) potential changes in the frequency or intensity of episodic disturbances such as fire, floods, or drought, and
    - (3) alterations in river and groundwater management.
- Overall, future riparian ecosystem trajectories will emerge from complex interactions among biotic, abiotic, and anthropogenic drivers
- VI and ET time series analysis will provide insights about long-term environmental trends and help to depict future scenarios.
- ***Our goal in future work is to answer***:
- *Are riparian corridors declining in the Lower Colorado River Basin?; How much is due to plant cover loss or defoliation alone?; How much is due to changing precipitation and temperatures or groundwater flux?; Is improvement seen in restoration sites?; Is restoration mitigating defoliation and at what scale?*

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Questions

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Eduardo Jiménez Hernández, Ph.D.

eduardojh@arizona.edu

Vegetation Index and Phenology (VIP) Research Group, Biosystems Engineering, University of Arizona

Biosystems Engineering

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